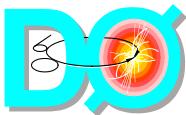


Jet Measurements at using a k_T Algorithm

Ursula Bassler
LPNHE, Paris

on behalf of the DØ collaboration



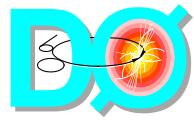
Outline

- Introduction: k_T jet algorithm @ D0
- **ABS 350: Inclusive Jet Cross Section**
Phys. Lett. B525 211, 2002 (hep-ex/0109041)
- **ABS 407: Sub-jet Multiplicities**
Phys. Rev. D65 052008, 2002 (hep-ex/0108054)
- **ABS 421: Thrust Cross Sections**
Preliminary

D0 Run I $p\bar{p}$ Data at $\sqrt{s} = 1800 \text{ GeV} \& 630 \text{ GeV}$

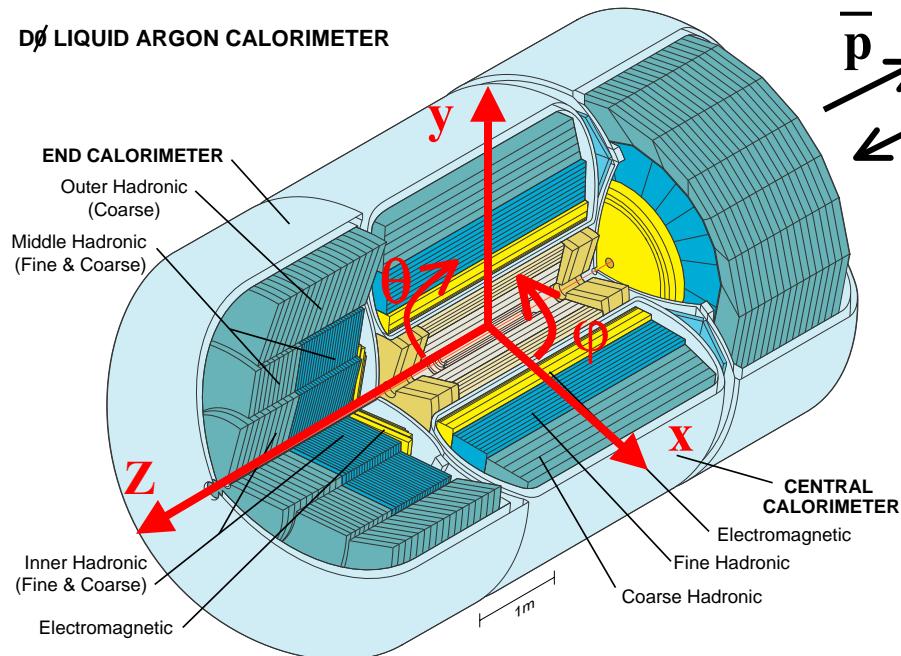
Run IB (94-95)
 $\sim 90 \text{ pb}^{-1}$

Run 1C (95)
 $\sim 600 \text{ nb}^{-1}$

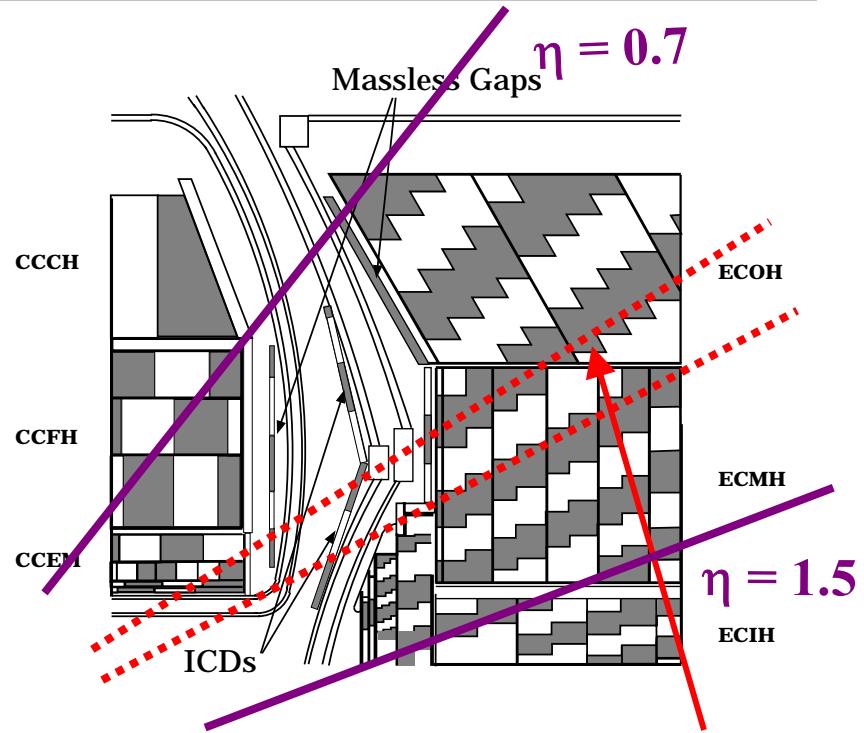


- Calorimeter

D ϕ LIQUID ARGON CALORIMETER



$$\bar{p} \quad p$$



- Liquid Ar/Ur calorimeter:
high granularity, good
hermeticity, quasi-compensated

$$\eta = -\ln [\tan(\theta/2)]$$

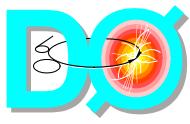
$$|\eta| < 4.2 \quad \lambda_{int} > 7.2 \text{ (total)}$$

- Transverse segmentation (towers)

$$\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$$

Electrons: $\sigma_E / E = 15\% / \sqrt{E} + 0.3\%$

Pions: $\sigma_E / E = 45\% / \sqrt{E} + 4\%$



Run I k_T Algorithm

Jet Algorithms:

- Fixed cone: most DØ Run I results, all CDF results

- k_T -algorithm: New DØ Run I results:

- **fewer split-merge ambiguities,**
- **infrared safe to all orders in perturbation theory.**

*Ellis, Soper Phys. Rev. D48 3160, 1993
Catani, Dokshitzer, Seymour, Webber
Nucl. Phys B406 187, 1993*

For each object and pair of objects:

$$d_{ij} = k_{T,j}^2$$
$$d_{ij} = \min(k_{T,i}^2, k_{T,j}^2) \frac{\Delta R_{ij}^2}{D^2}$$

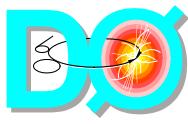
Soft Resolution parameter ($D=1$)

Collinear (if $\Delta R << 1$)

order all d_{ii} and d_{ij} :

If $d_{\min} = d_{ij}$
⇒ merge particles

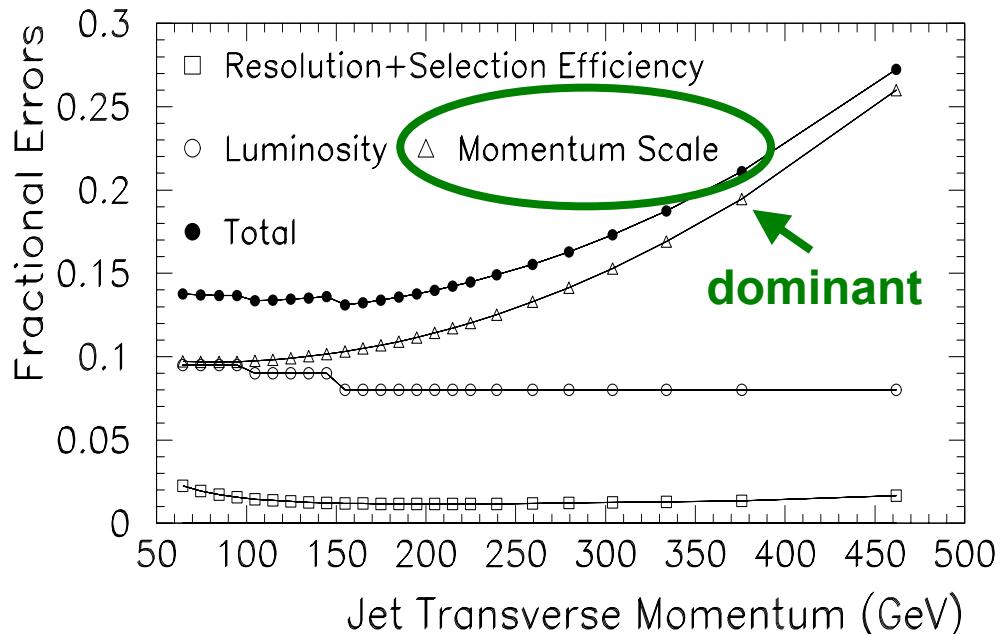
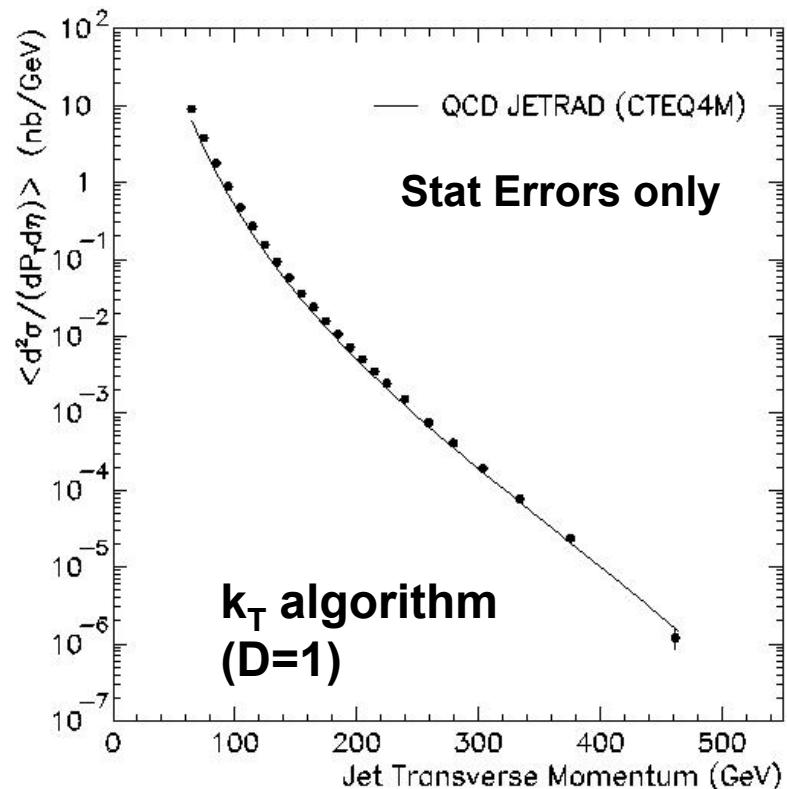
If $d_{\min} = d_{ii}$
⇒ jet



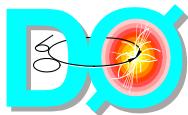
Inclusive Jet Cross Section

⇒ pQCD predictions, proton structure, quark compositeness

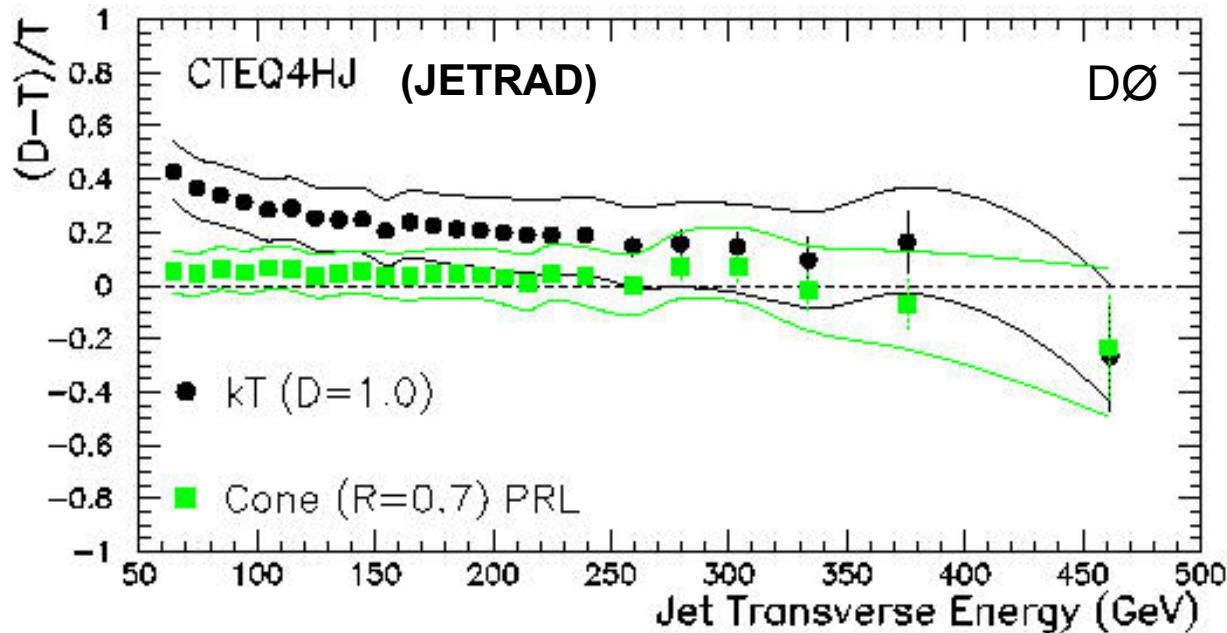
$$\left\langle \frac{d^2\sigma}{dP_T dn} \right\rangle (p\bar{p} \rightarrow \text{jet} + X) = \frac{N}{\Delta p_T \cdot \Delta \eta \cdot L} \cdot \frac{C_{\text{JES}} C_{\text{Resol}}}{\epsilon_{\text{ff}}} \quad \text{versus } P_T$$



Tot. Err = 14 (27)% at 60 (450) GeV

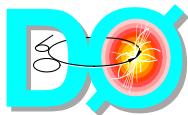


Comparison with Cone Result

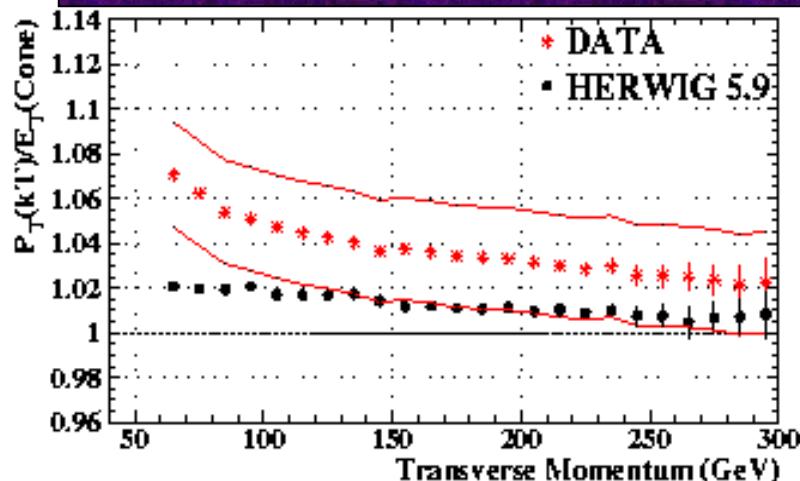


Each result is
compared to its own
NLO prediction

- k_T vs. cone agreement is reasonable; marginal at low P_T
 - NLO predictions: $\sigma(k_T, D=1) = \sigma(\text{cone}, R=0.7)$ within 1%
- the data is corrected back to particle level
- error correlations are large point-to-point in p_T , but largely uncorrelated between the two measurements.



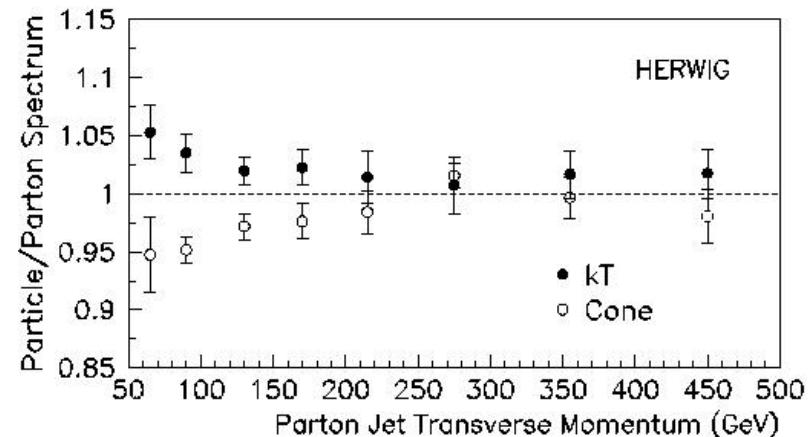
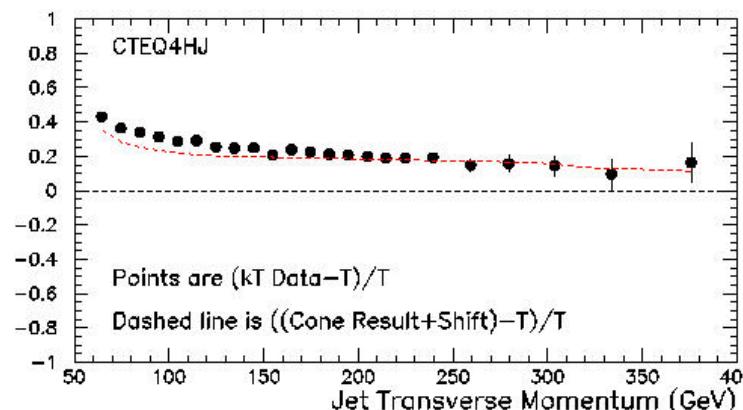
Hadronization effects

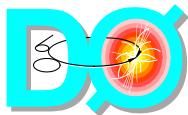


→ k_T jets are 7 (3)% more energetic at 60 (200) GeV than cone jets:
• consistent with HERWIG at high p_T ,
at 2σ at low p_T

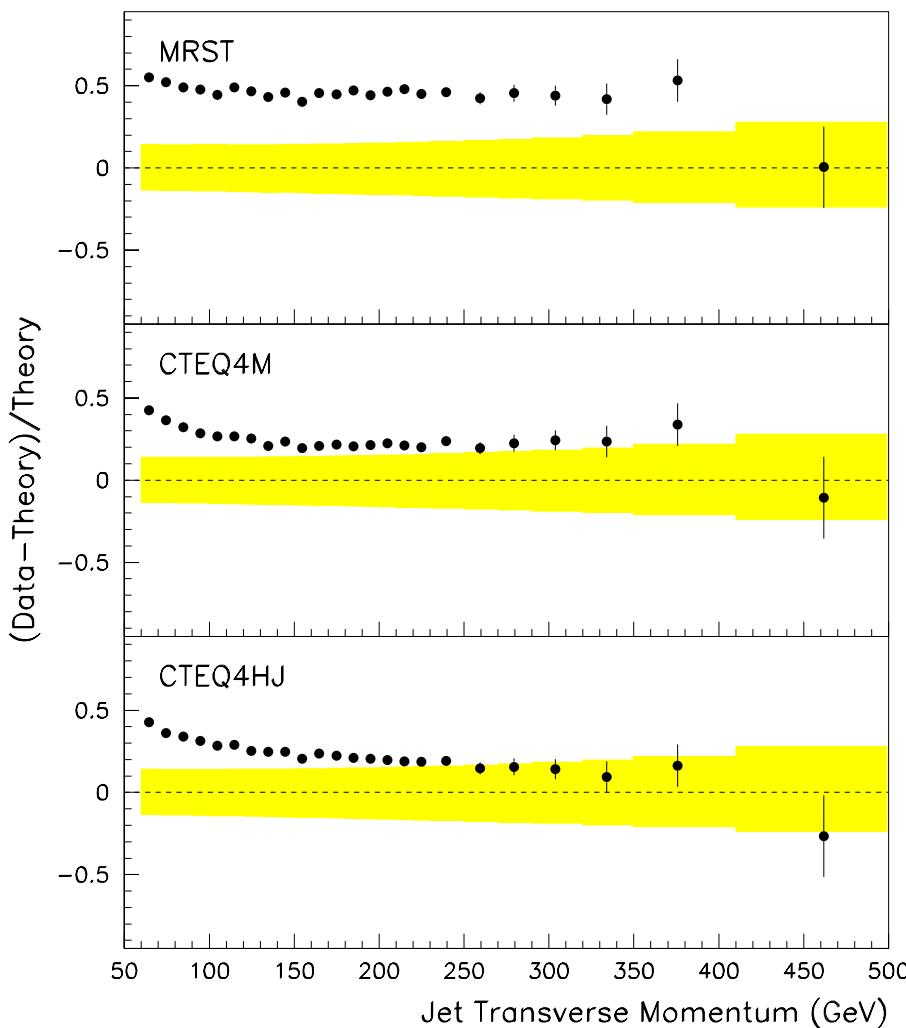
- particle jets are more (less) energetic than parton jets with k_T (cone)
- k_T collects more energy
- cone losses energy

applying correction to
cone-jets improves
agreement between
the 2 algorithms





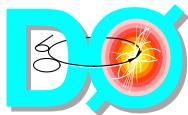
Comparisons with pdf's



- MRST: nearly constant offset
- CTEQ4M: improved description at high p_T
- CTEQ4HJ: better χ^2 , especially at high p_T

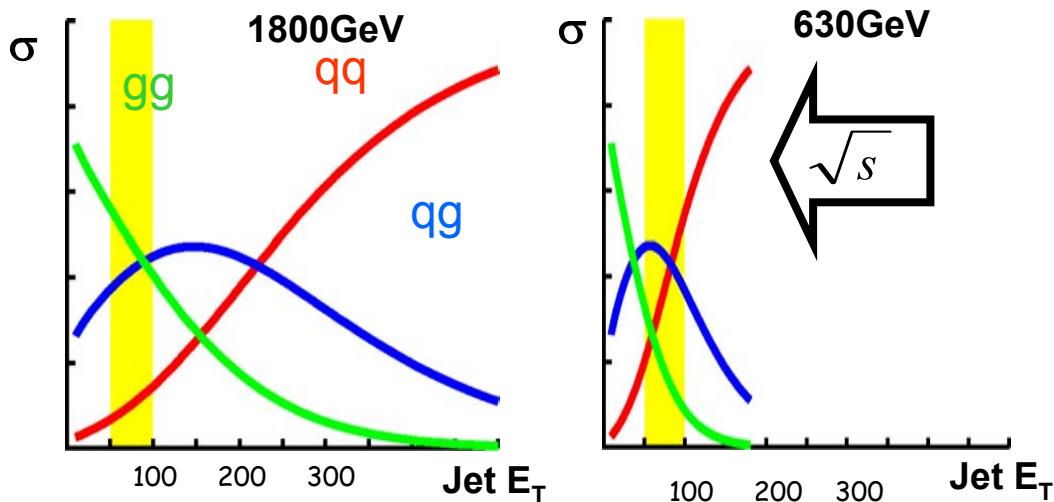
all data points		
pdf	$\chi^2(\text{ndf}=24)$	prob(%)
CTEQ3M	37.6	3.8
CTEQ4M	31.2	15
CTEQ4HJ	27.2	29

p _T > 100 GeV only		
pdf	$\chi^2(\text{ndf}=20)$	prob(%)
CTEQ3M	17.4	62.7
CTEQ4M	15.8	72.7
CTEQ4HJ	15.1	77.3



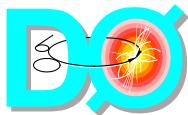
Multiplicity in Quark & Gluon Jets

- Test of QCD: difference between quark & gluon jets
 - ratio of color factors of gluons radiated from gluons/quarks = 9/4
 - ~ multiplicity of objects in gluon/quark jets at asymptotic limit
 - particles in a gluon jet are softer than in a quark jet
- Separate quark from gluon jets: top, Higgs, W+Jets events



at fixed Jet E_T quark/gluon jet contribution to the total x-section vary with \sqrt{s}

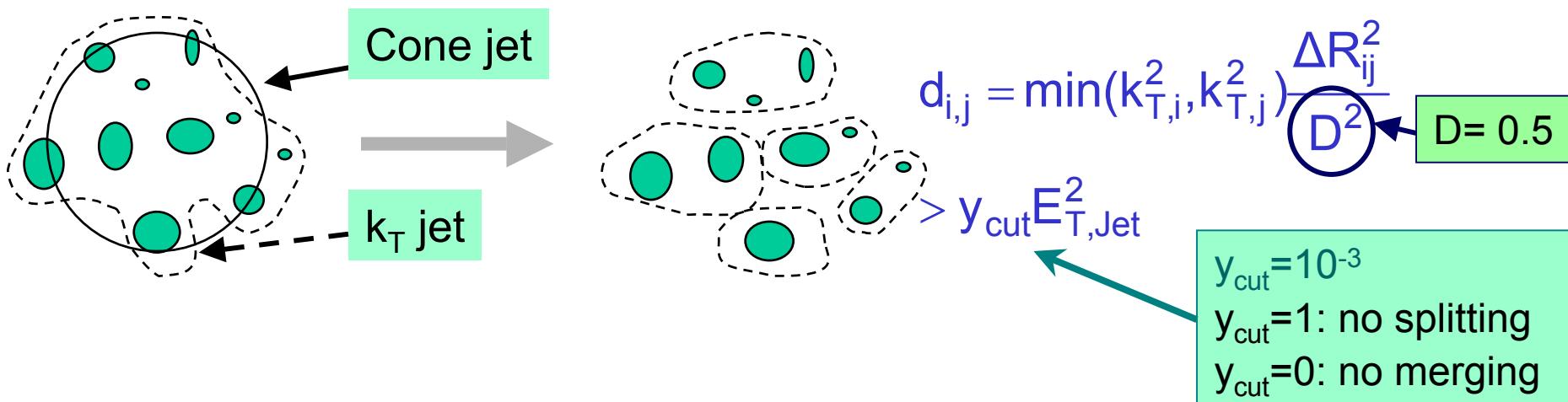
⇒ measure the sub-jet multiplicity in quark and gluon jets



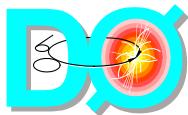
Sub-jets with the k_T algorithm

Merge criteria adjusted to study jet structure:

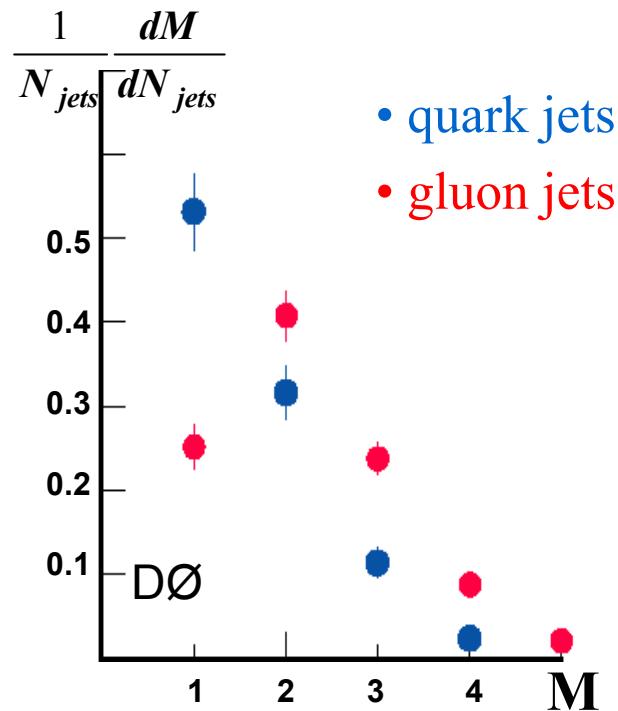
- re-run k_T algorithm on all particles already assigned to a jet



- determine gluon jet fraction f_g from MC: $f_{1800}=0.59$ $f_{630}=0.33$ ($55 < E_T < 100$ GeV)
- sub-jet multiplicity defined as: $M = f_g M_g + (1-f_g) M_q$
- assuming sub-jet multiplicity independent of \sqrt{s}
- ⇒ extract gluon (M_g)/quark (M_q) sub-jet multiplicities from data at 1800 and 630 GeV



Sub-jets in Quark & Gluon Jets

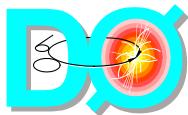


- gluon jets have a higher sub-jet multiplicity as expected
- good description by HERWIG
- dominant uncertainties:
 - quark/gluon jet fraction, dependent on pdf
 - jet energy scale
- result qualitatively in agreement with resummation calculation from Forshaw & Seymour

$$R \equiv \frac{\langle M_g \rangle - 1}{\langle M_q \rangle - 1} \quad R = 1.84 \pm 0.15 \text{ (stat)} \pm \begin{matrix} 0.22 \\ 0.18 \end{matrix} \text{ (sys)}$$

HERWIG: 1.91

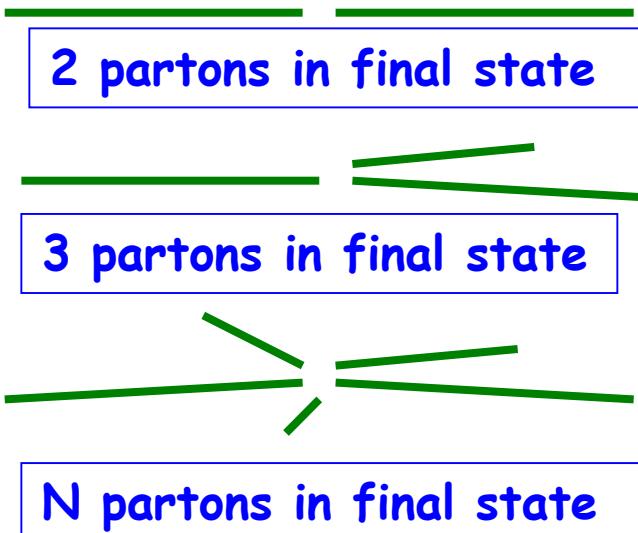
ALEPH (e^+e^-): 1.7 ± 0.1



Event Shape Variable: Thrust

Event shape variables allow to:

- study spatial distribution of hadronic final states
- test perturbative QCD, verify resummation calculations
- extract α_s



$$T=1$$

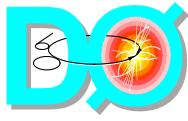
$$T=[2/3,1] \\ (\text{LO})$$

$$T=[1/2,1] \\ (\text{N...NLO})$$

$$T = \max_{\hat{n}} \frac{\sum_i |\vec{p}_i \cdot \hat{n}|}{\sum_i |\vec{p}_i|}$$

\hat{n} : direction which maximizes T
 i : number of partons/particles/jets in an event

Thrust characterizes sphericity of an event

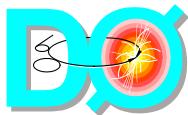


Thrust at hadron colliders

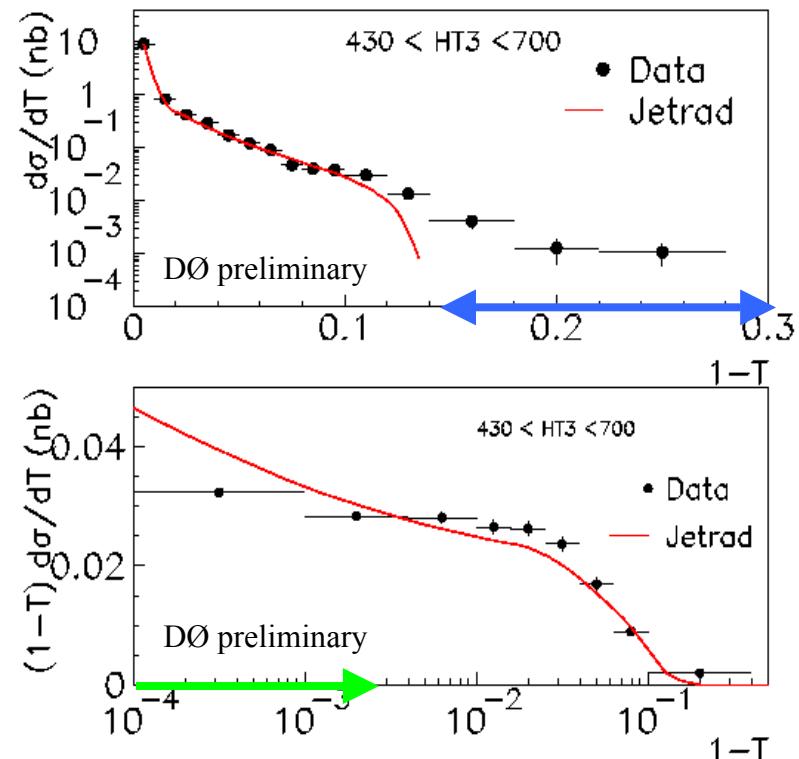
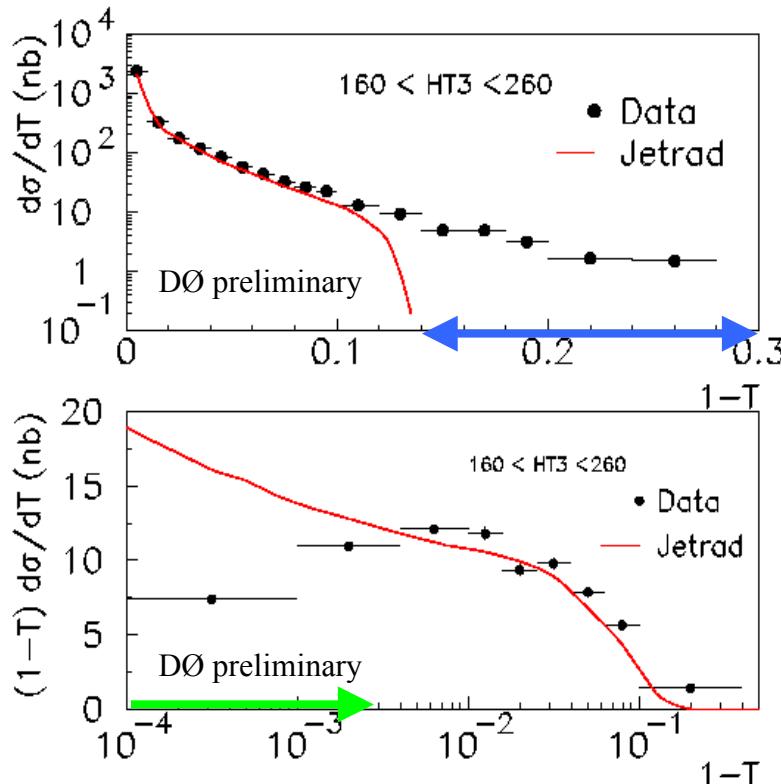
- **difficulties:** underlying event, pile-up, multiple interactions
 - ⇒ define thrust from 2 leading jets in thrust T_2
- **thrust is not Lorentz invariant**
 - ⇒ introduce Transverse Thrust T_2^T computed from p_t

$$T_2^T = \max_{\hat{n}} \frac{\sum_i |\vec{p}_{ti} \cdot \hat{n}|}{\sum_i |\vec{p}_{ti}|}$$
$$\sqrt{2}/2 \leq T_2^T \leq 1$$

- **x-sect in bins of $H_{3T} = \sum_{i \leq 3} |\vec{p}_{ti}| \propto Q^2$ on parton level**



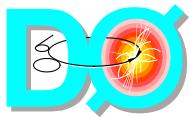
Dijet Transverse Thrust x-section



- Disagreement with JETRAD calculation in 2 regions:

⇒ $\sqrt{2}/2 \leq T_2 \leq \sqrt{3}/2$: LO calculation is $O(\alpha_s^4)$, $O(\alpha_s^3)$ not over whole range

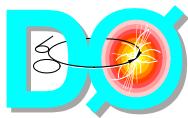
⇒ limit $(1-T) \ll 1 \rightarrow$ emission of soft and collinear gluons → logarithmic terms in $\ln(1-T)$ → resummation needed



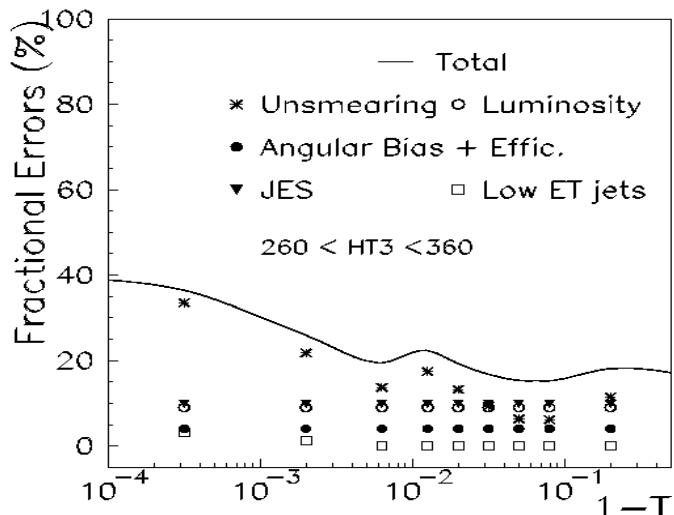
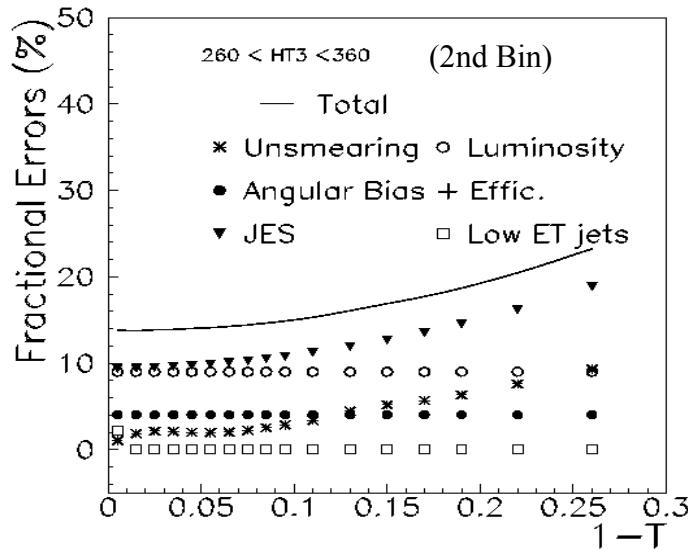
Summary

- DØ has successfully implemented and calibrated a k_T jet algorithm in a hadron collider
 - ⇒ comparison of the k_T x-section, cone x-section and NLO calculations at low p_t opened a discussion on matters such us hadronization, underlying event and algorithm definition
 - ⇒ quark & gluon jets have a different structure, consistent with HERWIG predictions
 - ⇒ thrust distributions offer an excellent opportunity to test the recently developed NLO 3-jet generators

Run 2 offers a unique opportunity to improve the understanding of jets in hadron colliders!



Systematic Uncertainties



Error Source	1st HT3 Bin Order of Magnitude (%)	2nd Bin Order of Magnitude (%)	3rd Bin Order of Magnitude (%)	4th Bin Order of Magnitude (%)
Luminosity	8	8	8	8
Unfolding	1 – 8	1 – 9	1 – 12	1 – 12
Pos Biases + Effic	4	4	4	4
Low energy jets	0 – 4	0 – 2	0 – 2	0 – 2
Mom Scale	10 – 15	10 – 18	10 – 20	10 – 20

Error Source	1st HT3 Bin Order of Magnitude (%)	2nd Bin Order of Magnitude (%)	3rd Bin Order of Magnitude (%)	4th Bin Order of Magnitude (%)
Luminosity	8	8	8	8
Unfolding	10 – 85	10 – 30	5 – 20	5 – 20
Pos Biases + Effic	4	4	4	4
Low energy jets	0 – 5	0 – 3	0 – 2	0 – 2
Mom Scale	10	10	10	10